HYPERSPECTRAL REMOTE SENSING OF NONFORESTED MONTANE VEGETATION COMMUNITIES

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ABSTRACT

Nonforested herbaceous vegetation communities represent a key ecosystem in montane environments, providing habitat for a diverse range of animal species. The montane meadow cover types occur below timberline, but are ecologically and geographically distinct from lower-elevation nonforested intermontane parklands. The objective of this project was to evaluate close-range hyperspectral data and simulated SPOT data as a tool for predicting the plant species composition of the meadows. Thirty montane meadow plots, representing a gradient from hydric to xeric conditions, were sampled in the Gallatin National Forest for spectral, biophysical, and botanical characteristics during 1998. Estimates of plant cover at the species level and measurements of spectral reflectance using an ASD 512-band spectroradiometer were made for each quadrat. Using a species dominance index, cover estimates for ten plant species were selected for the analysis. Simulated SPOT bands were derived from the spectroradiometer data and the two spectral data sets were entered separately into principal components analysis (PCA). Using the spectral components, binary logistic regression models determined the probability of the dominant plant species occurring in the montane meadows. The results indicate that the presence of several plant species could be successfully predicted using either spectral data set.

1.0 INTRODUCTION

This paper represents one component of a larger project examining ecological dynamics in the Greater Yellowstone Ecosystem (GYE), concentrating specifically upon the spatial and temporal dynamics of montane vegetation communities. The long-term goal of the project is to develop predictive species assemblage models based upon landscape level habitat analysis. This involves using intensive, local field sampling to test for relationships between species distribution patterns and remotely sensed data. If patterns of spectral response can be linked to distinct plant species assemblages, this may provide a means to predict potential plant and animal species diversity (Walker et al., 1992; Stoms and Estes, 1993; Jorgenson and Nohr, 1996; Nagendra and Gadgil, 1999).

Nonforested herbaceous vegetation communities represent a key ecosystem in high-altitude environments, providing forage for both native and domesticated grazers. These land cover types occur below timberline, but are ecologically and geographically distinct from lower-elevation nonforested intermontane parklands. The species composition and vegetation condition of montane meadow communities are closely linked to environmental conditions. Because vegetation composition and structure governs the spectral reflectance of meadows, spectral

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response characteristics can be linked to plant species or species assemblages to identify areas of high potential biodiversity (Nagendra, 2001; Debinski and Humphrey, 1997). Remote sensing technology has been successfully used to characterize, map, and monitor other nonforested vegetation communities (e.g., grasslands and intermountain shrublands), but relatively little attention has been directed toward characterizing the vegetation of higher-elevation montane meadows.

The objective of this project was to evaluate close-range hyperspectral remote sensing as a tool for predicting the plant species composition of montane meadows. Because plant species with dominant cover play greatly influence reflectance patterns as measured by satellite, it is essential to first test the relationship between remotely sensed data and plant communities. If plant species distribution patterns cannot be predicted using remotely sensed data, relationships between remotely sensed data and animal taxa would be highly unlikely. Ground-based investigations under controlled conditions are a necessary first step to explore spectral-ecological relationships and the predictability of specific plant species based on spectral reflectance before extrapolating such relationships to coarser-scale satellite remotely sensed imagery.

2.0 METHODS

2.1 STUDY AREA

The study area is located in the Gallatin National Forest northwest of Yellowstone National Park, USA. Yellowstone and Grand Teton National Parks, and the surrounding national forests form what has come to be known as the Greater Yellowstone Ecosystem (GYE). Geographically, Marston and Anderson (1991) roughly define the Greater Yellowstone Ecosystem as the Yellowstone Plateau and elevations above 2130 m in the surrounding region. At a local scale, the region includes a wide range of elevation and moisture gradients. Nonforested land cover types within the ecosystem range from hydric willow and sedge meadows to high-altitude tundra and rock meadows (Knight, 1994). The study area extends north-south from Porcupine Creek to Bacon Rind Creek and east-west from the crest of the Madison Range to the Gallatin Range, an area defined approximately by 111° 00' W - 111° 30' W, 44° 50' N - 45° 30' N.

2.2 MONTANE MEADOWS CLASSIFICATION

Multitemporal SPOT multispectral data from May 25, 1994 and September 6, 1994 were used to produce a map of meadows within the Gallatin National Forest to guide field sampling. Image data were georeferenced to a Universal Transverse Mercator (UTM) coordinate system, converted to reflectance, and combined into a six-band data file for classification. Unsupervised classification was used to produce a map of six meadow types (M1 to M6), representing a probable xeric-to-hydric gradient. To facilitate location of study sites during fieldwork, the map was converted to vector format and plotted on translucent Mylar, allowing overlay onto 1:24,000 scale USGS topographic maps of the study region. Field sampling was conducted at sites within polygons selected from the meadow classes. The sample sites were located in the field with the aid of aerial photography, topographic maps, and compass readings from identifiable landmarks. Particular care was taken to ensure that sites were located in the center of a class polygon.

2.3 FIELD SAMPLING

Five plots were sampled in each of the six meadow types (30 plots total) during July 1998. For spectral and botanical sampling, an array of twenty 1 m x 1 m quadrats arranged on a 4 x 5 grid were established within each 20m x 20 m plot. Ocular cover of all plant species was estimated using a modified Daubenmire (1959) technique for each of the twenty vegetation quadrats to derive a measure of plant species composition. Nadir-view spectral reflectance readings were taken using an Analytical Spectral Devices (ASD) VNIR spectroradiometer recording 512 discrete spectral bands over the range 326.5 - 1055.3 nm. Calibration measurements were taken at each plot from a $BaSO_4$ standard white reference. Ten spectroradiometer scans per quadrat were acquired and internally averaged by the ASD system to determine spectral reflectance for each quadrat. The twenty quadrat measurements were averaged to produce a mean spectral reflectance curve for each plot. Only those spectral bands ranging from 400nm to 900nm (352 bands) were used in the analysis.

2.4 DERIVED VARIABLES

Dominant species were identified using a dominance index. The dominance index was calculated by multiplying the percent of sites a species was present by the average percent cover occupied by a species. Species dominating 95% of the vegetation cover were selected for the analysis. The dominant species selected were bluebunch fescue (*Festuca idahoensis*), Kentucky bluegrass (*Poa pratensis*), big sagebrush (*Artemisia tridentata*), water sedge (*Carex aquatilis*), beaked sedge (*Carex rostrata*), wolf willow (*Salix wolfii*), common timothy (*Phleum pratense*), sticky geranium (*Geranium viscosissimum*), Nelson's needlegrass (*Stipa nelsonii*), and northwest cinquefoil (*Potentilla gracilis*).

The spectroradiometer data were aggregated to derive three additional spectral variables simulating spectral reflectance as measured by the SPOT High Resolution Visible (HRV) multispectral satellite sensor. The three simulated SPOT bands had bandwidths of 500-590 nm, 610-680 nm, and 790-890 nm.

Principal components analysis (PCA) was used to reduce and decorrelate the spectral data. Separate analyses were used for the two spectral data sets (spectroradiometer and simulated SPOT). Using spectroradiometer bands ranging from 400nm to 900nm, every other band (178 bands total) was entered into PCA. Of the 177 principal components generated, the first three components explained 99.4% of the variance in the original data set and were selected for subsequent analysis. Two principal components were derived from the simulated SPOT data and explained 99.64% of the variance in the original data set. The first and second components derived from each data set corresponded to visible and near-infrared components, respectively. The third component derived from the spectroradiometer data explained 1.453% of the variance and was difficult to interpret due to low factor loadings.

2.5 STATISTICAL ANALYSIS

Pearson's correlation coefficients were calculated to determine if there were significant relationships between the hyperspectral data and percent cover by species. Next, binary logistic regression analysis was used to determine whether spectroradiometer and/or simulated SPOT data could predict the presence of dominant plant species. The cover data for the ten most dominant species were coded into dichotomous dummy variables where the absence of a species was coded to zero and the presence (cover > 0%) was coded to one. To compare how spectroradiometer and simulated SPOT data could predict the presence of plant species in a montane meadow, principal components derived from the two spectral data sets were entered into separate logistic regression models.

3.0 RESULTS & DISCUSSION

3.1 GENERAL MEADOW CHARACTERISTICS

M1 meadows were dominated by willow species and were located near streams. M2 meadows were dominated by sedge species and usually had some standing water. M3 and M4 meadows were of medium moisture and dominated by cinquefoil (*Potentilla gracilis*) and mixed herbaceous vegetation, while M5 and M6 meadows were characteristically xeric, rocky, and dominated by sagebrush (*Artemisia tridentata*). Plant species distinctive to specific meadow types include: *Salix wolfii*, *Aster integrifolius* (M1), *Carex rostrata*, *Juncus balticus* (M2), *Achillea millefolium*, *Artemisia cana* (M3), *Potentilla gracilis*, *Geranium viscocissimum* (M4), *Festuca idahoensis*, *Aster campestris* (M5), and *Artemisia tridentata*, *Stipa nelsonii* (M6) (Debinski *et al.*, 1999).

3.2 CORRELATION ANALYSIS

Correlation coefficients indicate that percent cover estimates of several species were significantly correlated with the close-range hyperspectral data (Figure 2; Critical r = 0.463). Of the ten species, percent cover estimates of six species were not significantly correlated with the spectroradiometer data. *Artemisia tridentata*, *Festuca idahoensis*, *Salix wolfii* and *Stipa nelsonii* were the four species having cover estimates that were significantly correlated with the close-range hyperspectral data. *Artemisia tridentata* and *Festuca idahoensis* were most highly correlated with the hyperspectral data with 98% and 92%, respectively, of the calculated correlation coefficients being significant.

There were distinct differences in the patterns of the correlation coefficients across the spectrum (Figure 2). Percent cover of *Festuca idahoensis*, *Geranium viscosissimum*, and *Artemisia tridentata* were positively correlated with spectral bands in the visible portion of the electromagnetic spectrum (0.4-0.7 nm) and negatively correlated with bands in the near-infrared (0.7-0.9 nm). In contrast, percent cover of the remaining seven species were negatively correlated with the visible region and positively correlated with the near-infrared region. These ten species may be illustrating a moisture gradient that exists among the six meadow types. *Festuca idahoensis* and *Artemisia tridentata* are found predominantly on the more xeric meadows such as M4, M5, and M6, and exhibit a spectral response pattern strongly influenced by exposed soil and rock.

3.3 LOGISTIC REGRESSION ANALYSIS

The logistic regression constants and coefficients using spectral components from the spectroradiometer and simulated SPOT data are presented in Tables 1 and 2, respectively. Goodness-of-fit of the twenty logistic regression models were assessed using the log likelihood chi-square statistic (Table 3). The log likelihood chi-square compares the likelihood ratio of the model with only the constant with the likelihood ratio of the model with all of the independent variables (Menard, 1995). The results show that the goodness-of-fit was significant for sixteen of the twenty or 80% of the models.

The predictive efficiency of the models was assessed using contingency tables. The tables show the accuracy of the predictions for both absence and presence of a species. The results obtained from the contingency tables indicate that the presence of several plant species in the montane meadows can be accurately predicted using the models derived from both sets of spectral components (spectroradiometer and simulated SPOT) (Table 4). While the percent correctly classified varied by species, most species were more than 66% correctly classified.

The spectroradiometer and simulated SPOT data varied in their ability to correctly predict the probability of the absence and presence of certain species. Models predicting the probability of the presence of *Festuca idahoensis*, *Artemisia tridentata*, and *Salix wolfii* fit the data relatively well with large chi-square values and a high percentage of correctly classified observations. Meanwhile, models predicting the probability of the presence of *Phleum pratense*, *Geranium viscosissimum*, and *Potentilla gracilis* fit the data relatively poorly with small chi-square values and a low percentage of observations correctly classified. As previously discussed the percent cover of six species was not significantly correlated with the spectroradiometer data. These three species were among those six and were also less dominant in the meadows than *Festuca idahoensis*, *Artemisia tridentata*, and *Salix wolfii*.

4.0 CONCLUSIONS

Results indicate that dominant plant species of montane meadows can be predicted with a high level of probability using either PCA-reduced hyperspectral data or simulated SPOT spectral bands. The next logical step would be to apply the predictive relationships to SPOT multispectral image data to produce probability maps for the occurrence of each species. Individual per-species maps then could also be combined to produce probability maps indicating levels of plant biodiversity. Such maps, either of individual species or species diversity, would be of significant value for guiding onsite field sampling, for monitoring probable changes in plant species diversity over time, and for directing field sampling of animal species (e.g., butterflies) that may have specific host-species relationships.

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Figure 1. The study are, Gallatin National Forest is located northwest of Yellowstone National Park, USA and is part of the Greater Yellowstone Ecosystem (GYE).

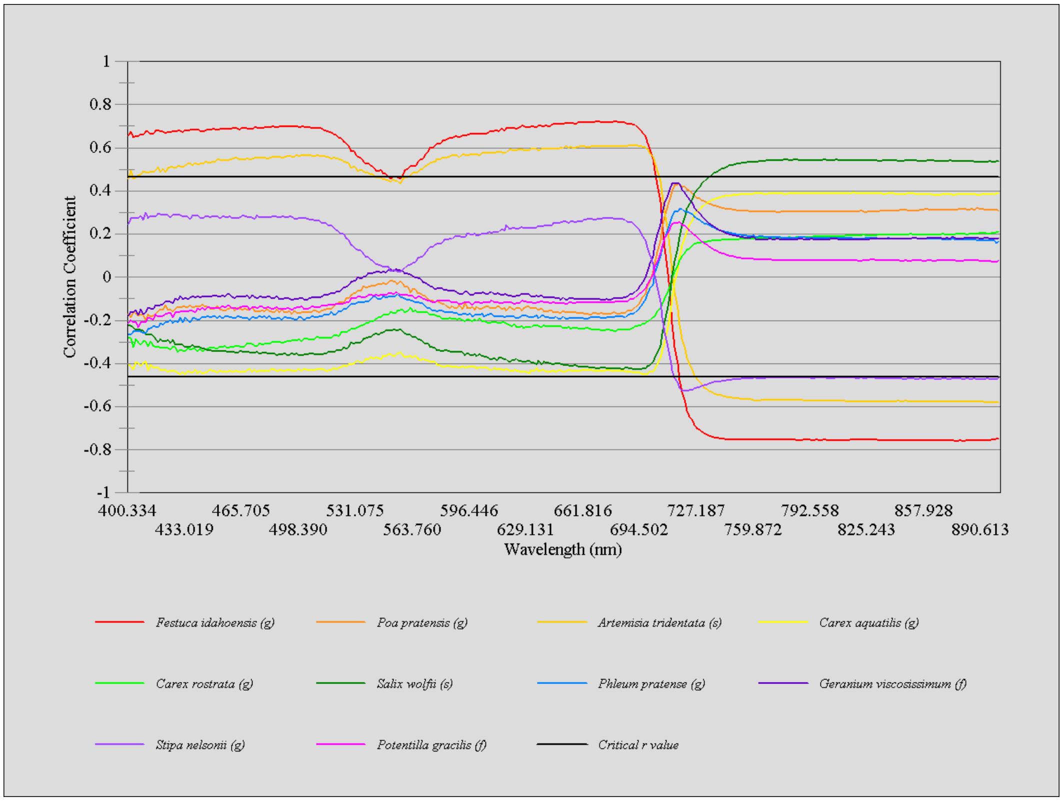

Figure 2. By-band plot showing Pearson's correlation coefficients between percent cover of dominant species and hyperspectral data.

Table 1. Logistic regression coefficients and significance values calculated using spectral components derived from spectroradiometer measurements.

		Component 1		**Component 2**		**Component 3**	
Species	*Constant*	**β**	**Sig. Value**	**β**	**Sig. Value**	**β**	**Sig. Value**
Festuca idahoensis	1.825	3.312	*0.0368	-2.311	*0.0319	0.492	0.5184
Poa pratensis	6.204	-2.074	0.2432	2.396	0.4752	2.698	0.1960
Artemisia tridentata	1.127	2.598	*0.0459	-2.141	*0.0166	0.696	0.3628
Carex aquatilis	-2.072	-1.718	0.1186	2.254	*0.0406	0.218	0.7565
Carex rostrata	-2.330	-2.333	0.0508	2.187	0.0508	0.637	0.3744
Salix wolfii	-2.040	-2.598	*0.0334	1.637	0.0520	-0.363	0.5713
Phleum pratense	0.464	-0.102	0.7915	0.864	*0.0491	0.131	0.7562
Geranium viscosissimum	-0.539	-0.299	0.5461	0.248	0.5841	1.019	*0.0315
Stipa nelsonii	0.468	1.958	*0.0245	-0.836	0.0969	0.734	0.1705
Potentilla gracilis	1.638	0.581	0.3644	0.364	0.4875	-0.718	0.1948

* Significant at alpha = 0.05

Table 2. Logistic regression coefficients and significance values calculated using spectral components derived from simulated SPOT bands.

Species	Constant	Component 1 β	Component 1 Sig. Value	Component 2 β	Component 2 Sig. Value
Festuca idahoensis	1.935	3.893	*0.0264	0.014	0.9904
Poa pratensis	11.431	-12.435	0.2514	5.616	0.2990
Artemisia tridentata	1.381	3.640	*0.0171	-0.336	0.7624
Carex aquatilis	-1.803	-3.364	*0.0177	1.346	0.1981
Carex rostrata	-1.673	-2.786	*0.0237	0.750	0.4346
Salix wolfii	-2.082	-2.893	**0.0037	0.149	0.8852
Phleum pratense	0.466	-1.316	0.0570	0.907	0.1662
Geranium viscosissimum	-0.412	-0.228	0.7063	-0.030	0.9612
Stipa nelsonii	0.598	1.367	0.0725	0.852	0.3155
Potentilla gracilis	1.432	-0.399	0.5865	0.625	0.4083

* Significant at alpha = 0.05 ** Significant at alpha = 0.01

Table 3. Log likelihood chi-square and corresponding significance values.

Species	Spectroradiometer Components χ^2	Spectroradiometer Components Sig. Value	Simulated SPOT Components χ^2	Simulated SPOT Components Sig. Value
Festuca idahoensis	22.919	**0.0000	21.995	**0.0000
Poa pratensis	16.984	**0.0007	13.466	**0.0012
Artemisia tridentata	22.454	**0.0001	21.546	**0.0000
Carex aquatilis	14.794	**0.0020	14.562	**0.0007
Carex rostrata	14.437	**0.0024	13.168	**0.0014
Salix wolfii	17.389	**0.0006	16.329	**0.0003
Phleum pratense	4.685	0.1964	4.243	0.1199
Geranium viscosissimum	6.209	0.1019	0.426	0.8081
Stipa nelsonii	15.357	**0.0015	13.200	**0.0014
Potentilla gracilis	3.296	0.3482	0.719	0.6981

* Significant at alpha = 0.05 ** Significant at alpha = 0.01

Table 4. The percent of observations correctly classified in the binary logistic regression models.

	Spectroradiometer Components			**Simulated SPOT Components**		
Species	Absence (%)	Presence (%)	Overall (%)	Absence (%)	Presence (%)	Overall (%)
FESTUCA IDAHOENSIS	90.91	94.74	93.33	90.91	89.47	90.00
Poa pratensis	75.00	96.15	93.33	75.00	92.31	90.00
Artemisia tridentata	83.33	88.89	86.67	83.33	77.78	80.00
Carex aquatilis	90.48	66.67	83.33	90.48	66.67	83.33
Carex rostrata	85.71	77.78	83.33	90.48	66.67	83.33
Salix wolfii	95.24	66.67	86.67	95.24	66.67	86.67
Phleum pratense	50.00	88.89	73.33	58.33	88.89	76.67
Geranium viscosissimum	72.22	50.00	63.33	100.00	0.00	60.00
Stipa nelsonii	69.23	76.47	73.33	76.92	76.47	76.67
Potentilla gracilis	0.00	91.67	73.33	0.00	100.00	80.00

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